Recent Developments in Strongly-Correlated Quantum Matter

Nordita (16 Jun - 2 Jul 2022)

Book of abstracts

Program block 1

Thursday, 16 Jun

13:30 – 14:30 Aharon Kapitulnik (Stanford University)

Thermal diffusion without well-defined quasiparticles

We present high-resolution thermal diffusivity measurements on several near optimally doped electron- and hole-doped cuprate systems in a temperature range that passes through the Mott-Ioffe-Regel limit, above which the quasiparticle picture fails. Our primary observations are that the inverse thermal diffusivity is linear in temperature and can be fitted to D=aT+b. The slope a is interpreted through the Planckian relaxation time τ≈h/kBT and a thermal diffusion velocity v_B, which is close, but larger than the sound velocity. The intercept b≈h/m represent a crossover (quantum) diffusion constant that separates coherent from incoherent quasiparticles. These observations suggest that both phonons and electrons participate in the thermal transport and both reach the Planckian limit for relaxation time. Where itinerant electrons are absent, a similar behavior is obtained for the insulating phases where the constant b is absent. We further discuss transport in the vicinity of charge density wave, where in the critical regime the observed behavior corresponds to a strongly coupled electron-phonon critical `soup.'

14:45 – 15:45 Sergej Moroz (Karlstad University)

Two-dimensional Ising gauge theory coupled to single-component fermion matter: topological order, confinement and U(1) deconfined criticality

I will present our investigations of the rich quantum phase diagram of Wegner's theory of discrete Ising gauge fields interacting with U(1) symmetric single-component fermion matter hopping on a two-dimensional square lattice. In particular limits the model reduces to (i) pure Z_2 even and odd gauge theories, (ii) free fermions in a static background of deconfined Z_2 gauge fields, (iii) the kinetic Rokhsar-Kivelson quantum dimer model at a generic dimer filling. I will introduce a local transformation that maps the lattice gauge theory onto a model of Z_2 gauge-invariant spin 1/2 degrees of freedom. In the absence of the magnetic plaquette term, I will present evidence of topologically ordered Dirac semimetal and staggered Mott insulator phases at half-filling. I will discuss the nature of the phase transition between these phases and present some arguments for deconfined U(1) criticality. At strong coupling, the lattice gauge theory displays fracton phenomenology with isolated fermions being completely frozen and dimers exhibiting restricted mobility. In that limit, I will argue that in the ground state dimers form compact clusters, whose hopping is suppressed exponentially in their size.

Friday, 17 Jun

11:00 – 12:00 Koenraad Schalm (Leiden University)

Holographic and Cuprate Strange Metals: A Tale of Two Sectors/Components

We review how both holographic and cuprate strange metals display signatures that suggest two separate sets of dynamical electronic degrees of freedom at play. These two sectors/two components show up in transport, single fermion response (ARPES) and two-fermion response (EELS).

14:00 – 15:00 Andrea Cavalleri (Max Planck Institute for the Structure and Dynamics of Matter)

Photo-induced High Temperature Superconductivity

I will discuss how coherent optical pulses at mid infrared frequencies can be used to excite targeted molecular vibrations in organic materials with strongly correlated electrons and manipulate their electronic properties. I will discuss especially the case of charge transfer salts and of doped fullerites. Both materials exhibit colossal increase in carrier mobility for certain vibrational excitations and key signatures of photo-induced high temperature superconductivity.
References
http://qcmd.mpsd.mpg.de/files/qcmd-theme/publications/2020/buzzi-Prx-10031028.pdf
http://qcmd.mpsd.mpg.de/files/qcmd-theme/publications/2018/cantalupi-NaPhys-2018.pdf
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http://qcmd.mpsd.mpg.de/files/qcmd-theme/publications/2016/mitrano-k3c60nat-2016.pdf

Saturday, 18 Jun

11:00 – 12:00 Erik van Heumen (University of amsterdam)

Disentangling Carrier Density and Momentum Relaxation in Cuprate Superconductors

One of the key mysteries in the cuprate phase diagram is the strange metallic phase, which features a variety of anomalous electronic properties. In recent years, various (magneto-) transport experiments have reported a singular behavior of the carrier density near a critical doping around p = 0.2 holes/Cu and these results have been interpreted as essential features of the strange metal response.
I will review these results considering the doping evolution of the optical conductivity across the phase diagram for the single layer material Bi2201. Whereas transport experiments only probe a combination of momentum relaxation and carrier density, the optical response enables us to disentangle the two. I will show that the doping and temperature evolution of the resistivity can be fully understood from changes in the momentum relaxation rate. At the same time, the carrier density displays a continuous and gradual evolution n ~ p across the phase diagram.
I will explain how these results provide new insight in the dynamics of the strange
metal phase.

14:00 – 15:00 Sera Cremonini (Lehigh University)

Black Holes, Higher Derivatives and Weak Gravity Constraints

In this talk I will discuss higher derivative corrections to black holes in AdS, and how the positivity of entropy and the weak gravity conjecture can be used to place bounds on their Wilson coefficients. In turn, this leads to new bounds on the central charges of the dual CFT and has new implications for transport.

Sunday, 19 Jun

11:00 – 12:00 Riccardo Arpaia (Chalmers University of Technology)

Strange metal from dynamical charge density fluctuations

The strange metal phase, which dominates large part of the phase diagram of cuprate high-Tc superconductors (HTS), is characterized by many peculiarities (e.g., linear in temperature resistivity, anomalous power-law decay in frequency of the Drude peak, linear in field magnetoresistance) which indicate that the Fermi-liquid theory, successfully used to describe even strongly correlated normal metals, fails to give a proper description of the physics at play. This peculiar phase exhibits a certain degree of universality: it has been found in many quantum materials (e.g., pnictides, heavy fermions, magic angle graphene), in conjunction with the presence of a quantum critical point (QCP) at zero temperature. However, in HTS superconductivity hinders the direct observation of a QCP at low temperatures: the description of the strange metal phase, both in terms of phenomenology (is there a QCP?) and of its constituent elements (how to describe this matter? Is it charge, spin or a mix of the two to be more relevant?) is far from being complete. The identification of fluctuations compatible with the strange metal phase would constitute a milestone to make a progress in the field.

In my talk, I will make a brief overview of charge density fluctuations (CDF). These excitations have been discovered in HTS only few years ago by resonant inelastic X-ray scattering (RIXS) [1,2], and theoretically associated for their properties to the long-sought microscopic mechanism behind the strange metal of cuprates. Phenomenologically, these fluctuations are indeed present over a wide region of the temperature-vs-doping phase diagram, pervading the whole strange metal phase, above the pseudogap temperature T*, where other charge/spin excitations disappear. Moreover, their modulation is very short-ranged, giving rise to a broad peak in the reciprocal space: CDF represent therefore an appealing candidate to mediate the isotropic scatting rate, equally affecting all the states on the Fermi surface, on which the famous linear-in-T resistivity is based [3]. Latest RIXS measurements allowed for the determination of the temperature and doping dependence of the CDF energy and intensity, and highlighted that CDF possess the right properties to be associated to a quantum phase transition and in particular to a QCP at a doping p*=0.19 [4]. These results support therefore the leading role of charge order in driving the anomalous properties of the strange metal in cuprate HTS.

[1] R.Arpaia et al., Science 365, 906 (2019).
[2] R. Arpaia and G. Ghiringhelli, J. Phys. Soc. Jpn. 90, 111005 (2021).
[3] G. Seibold et al., Commun. Phys. 4, 7 (2021).
[4] R.Arpaia et al., submitted (2022).

14:00 – 15:00 Alexander Krikun (Nordita)

Thermoelectric transport in holographic gapless charge density waves

I will explain how the thermo-electric transport properties in the strongly correlated quantum systems with emergent charge density waves can be studied via the holographic models, based on AdS/CFT duality. These models provide a calculable framework where phenomenology quite different from the conventional approaches can be explored. The useful outcome of this method is the generalization of hydrodynamic effective theory and its transport coefficients, which can in turn be used in the analysis of the real experiments. In this way the novel phenomenological analysis of the strongly correlated quantum systems with charge density waves can be developed.

Monday, 20 Jun

11:00 – 12:00 Luca Delacretaz (U Chicago)

Nonlinear bosonization of Fermi liquids

Landau's theory of Fermi liquids is a cornerstone of condensed matter physics. I will show how to formulate Fermi liquid theory as an effective field theory of bosonic degrees of freedom, using the formalism of coadjoint orbits. While at the linear level, this theory reduces to multidimensional bosonization, it necessarily features nonlinear corrections that are fixed by the geometry of the Fermi surface. These are crucial to reproduce nonlinear response and certain other aspects of Fermi liquid theory phenomenology that are not captured by current bosonization approaches. The effective field theory framework furthermore systematically parametrizes corrections to Fermi liquid behavior, and provides a new angle to approach non-Fermi liquids. (Based on https://arxiv.org/abs/2203.05004).

14:00 – 15:00 Joerg Schmalian (Karlsruhe Institute of Technology)

Pairing without quasiparticles: holographic superconductivity from the Yukawa SYK model

Superconductivity is abundant near quantum-critical points, where fluctuations suppress the formation of Fermi liquid quasiparticles and the Bardeen-Cooper-Schrieffer theory no longer applies. Two very distinct approaches have been developed to address this issue: quantum-critical Eliashberg theory and holographic superconductivity. The former includes a strongly retarded pairing interaction of ill-defined fermions, the latter is rooted in the duality of quantum field theory and gravity theory. We demonstrate that both are different perspectives of the same theory. We derive holographic superconductivity in form of a gravity theory with emergent space-time from a quantum many-body Hamiltonian - the Yukawa SYK model and finite-dimensional generalizations thereof - where the Eliashberg formalism is exact. Exploiting the power of holography, we then determine the dynamic pairing susceptibility of the model.

Wednesday, 22 Jun

9:00 – 9:45 Ilya Esterlis (Harvard University)

New large-N theories of non-Fermi liquids

Anomalous, or non-Fermi liquid, metallic behavior is ubiquitous in the phase diagrams of various interesting strongly correlated materials, often arising in the vicinity of quantum critical points. Despite the apparent lack of well-defined electronic quasiparticles, many of these non-Ferm liquids nevertheless go superconducting at low temperatures. I will discuss recent progress on a new class of large-N theories aimed at describing both non-Fermi liquid behaviors above Tc and also the nature of pairing in such incoherent systems. By employing random couplings in flavor space between fermions and bosonic degrees of freedom (such as a fluctuating order parameter or phonon), I will demonstrate that one can obtain (1) a controlled theory of a critical Fermi surface in two spatial dimensions and (2) a simple setting in which to study the interplay of non-Fermi liquid physics and superconductivity. We obtain various results well-known from the theory of metallic quantum criticality, albeit as a part of a systematic 1/N expansion. I will further demonstrate how both critical and fully incoherent electrons still undergo a superconducting transition and I will describe various properties of the resulting state, such as the possibility of a strongly coupled fluid of Cooper pairs below Tc.

9:45 – 10:30 Richard Davison (Heriot-Watt University)

Hydrodynamic diffusion and its breakdown near AdS2 fixed points

Hydrodynamics provides a universal description of interacting quantum field theories at sufficiently long times and wavelengths, but breaks down at scales dependent on microscopic details of the theory. In the vicinity of a quantum critical point, it is expected that some aspects of the dynamics are universal and dictated by properties of the critical point. I will discuss the breakdown of hydrodynamics in holographic states that are governed by AdS2 critical points in the IR. I will show that the local equilibration time characterising this breakdown is set by the scaling dimension of an operator at the critical point, and that the local equilibration length is set simply by the hydrodynamic diffusivity. I will confirm that these universal relations also hold in an SYK chain model in the limit of strong interactions.

11:00 – 11:45 Andrew Lucas (University of Colorado Boulder)

Spatially resolved electrical transport in correlated quantum materials

The resistivity of a metal is easy to measure but hard to compute. Indeed, some of the biggest mysteries in condensed matter physics revolve around simple bulk transport coefficients: e.g., the origin of T-linear resistivity in strange metals. In the coming decade, technologies such as nitrogen vacancy center magnetometry enable us to measure spatially local transport (e.g. wave number dependence in conductivity) with increasing ease, yet relatively few theories have actually calculated this quantity.

In this talk, I will highlight 3 recent experimental and theoretical developments towards using spatially local transport to reveal unconventional non-Ohmic transport in metals:
(1) The observation of (weakly) viscous fluid flow in graphene in multiple experiments;
(2) our use of holographic duality (AdS/CMT) to find tractable models for spatially local transport on Placnkian scales near certain quantum critical points
(3) our prediction of “analogue viscous current flow” in a 2D superconducting thin film just above the critical temperature.

11:45 – 12:30 Floriana Lombardi (Chalmers University of Technology)

Restoring the strange metal phase in underdoped cuprated via suppression of Charge Density Wave

The “strange metal” phase of High Critical Temperature Superconductors (HTS) is one of the most striking manifestations of the strong electron-electron correlation in these materials. It manifests at optimal doping as a linear temperature dependence of the resistivity that persists to the lowest T when superconductivity is suppressed. This behavior is fundamentally different from that observed in more conventional metals, where a T-linear dependence of the resistivity is found, only at high temperatures, where phonon scattering dominates the transport. For underdoped cuprates this behavior is lost below the pseudogap temperature T*, where Charge Density Waves (CDW) together with other intertwined local orders characterize the ground state of the material. The association between the departure from the T-linear resistivity and the occurrence of the pseudogap phenomenon has long been speculated. However, there is no consensus on the physics at play. To address the origin of the T-linear dependence departure in the underdoped regime we have tuned the ground state of underdoped the HTS by using the geometric modification of the unit cell under the strong strain induced by the substrate. We show that the T-linear resistivity of highly strained, nm thick and underdoped $YBa_2Cu_3O_{7-\delta}$ (YBCO) films is restored when the CDW amplitude, detected by Resonant Inelastic X-ray scattering, is suppressed. This observation points towards an intimate connection between the onset of CDW and the departure from the strange metal behaviour in underdoped cuprates, a link which was unclear up to now. At the same we also observe that the superconducting temperature onset and the upper critical field Hc2 are enhanced at dopings where the CDW is suppressed which supports the competition between charge order and superconductivity. These effects demonstrate how strain control and nanoscale dimentions allow to manipulate the ground state of HTS which is crucial to understand the complex physics of these materials.

14:00 – 14:45 Hong Liu (online) (MIT)

Quantum information of equilibrated pure states in quantum many-body systems and applications to black holes

We describe a general method for extracting universal quantum informational properties of a pure state that has equilibrated in a chaotic quantum many-body system. The method reveals a rich entanglement phase structure for quantum chaotic systems. In particular, we identify a regime where quantum negativities among subsystems can be extensive but the mutual information is sub-extensive, indicating a large amount of bound entanglement. When applied to evaporating black holes, these results explain the success of recent Euclidean gravitational path integral calculations, and make new predictions on quantum informational properties of Hawking radiations.

14:45 – 15:30 Stefano Bonetti (Stockhom University)

Terahertz-driven dynamical multiferroicity in SrTiO3

The theoretical concept of dynamical multiferroicity has been introduced to describe the emergence of magnetization by means of a time-dependent electric polarization in non-ferromagnetic materials. In simple terms, a large amplitude coherent rotating motion of the ions in a crystal induces a magnetic moment along the axis of rotation. However, the experimental verification of this effect is still lacking. Here, we provide evidence of room temperature magnetization in the archetypal paraelectric perovskite SrTiO3 due to this mechanism. To achieve it, we resonantly drive the infrared-active soft phonon mode with intense circularly polarized terahertz electric field, and detect a large magneto-optical Kerr effect. A simple model, which includes two coupled nonlinear oscillators whose forces and couplings are derived with ab-initio calculations using self-consistent phonon theory at a finite temperature, reproduces qualitatively our experimental observations on the temporal and frequency domains. A quantitatively correct magnitude of the effect is obtained when one also considers the phonon analogue of the reciprocal of the Einsten – de Haas effect, also called the Barnett effect, where the total angular momentum from the phonon order is transferred to the electronic one.

16:00 – 16:30 Lars Fritz (Utrecht University)

Role of electron-hole excitations in the thermoelectric response of hydrodynamic Dirac systems

We study the hydrodynamic near-equilibrium properties of ultraclean interacting two dimensional Dirac electrons within the Keldysh quantum field theoretical approach. We study it from a weak and a strong-coupling perspective. We demonstrate that long-range Coulomb interactions play two independent roles: (i) they provide the inelastic and momentum conserving scattering mechanism that leads to fast local equilibration; (ii) they facilitate the emergence of collective excitations, for instance plasmons, that contribute to transport properties on equal footing with electrons. Our approach is based on an effective field theory of this collective field coupled to electrons. Within a conserving approximation for the coupled system we derive a set of coupled quantum kinetic equations. This builds the foundation of the derivation of the Boltzmann equations for the interacting system of electrons and plasmons. From this, we explicitly derive all the conservation laws and identify the extra contributions of energy density and pressure from the plasmons. We demonstrate that plasmons show up in thermoelectric transport properties as well as quantities that enter the energymomentum tensor, such as the viscosity.

16:30 – 17:00 Andrea Amoretti (University of Genoa and INFN)

Magnetohydrodynamics, holography and cuprates

In this talk I will review recent developments in the construction of hydrodynamic theories in which translations are broken either spontaneously or pseudo-spontaneously, in the presence of a strong, external magnetic field.
I will show that Hall transport coefficients become important when the magnetic field is strong. Moreover I will prove that, using the Ward Identities of the theory, the hydrodynamic AC correlators can be expressed in terms of the DC conductivities (which can be measured in real condensed matter systems) and a couple of intrinsic scales (which can be extracted from AC correlators).
Finally, I will verify the validity of our hydrodynamic framework in well known holographic Q-lattice like theories. I will then show how the present results can be useful in testing the transport properties of the strange metal phase of cuprates.

9:00 – 9:45 Kamran Behnia (ESPCI)

Thermal transport and Quasi-particle hydrodynamics

Heat travels in solids thanks to mobile electrons and phonons, collective vibrations of atoms. Even in a detect-free solid, collisions degrade the flow due to the presence of the lattice. However, there are situations where a significant fraction of collisions for phonons, for electrons or for both conserve momentum. In this hydrodynamic regime, the quasi-particle viscosity plays a significant. Recent studies of thermal transport in a variety of solids such as strontium titanate [1], black phosphorus [2], graphite [3] reveal a narrow temperature window where normal collisions between phonons enhance thermal diffusivity. In the case of antimony, where one mobile electron is shared by one thousand atoms, the most frequent colliders of phonons at cryogenic temperatures are electrons, and not other phonons, defects or boundaries. This leads to a dissymmetric exchange where the energy flow of the phonon fluid is lost through collisions by electrons, but the energy and momentum flow of the electron fluid is not lost through collisions by phonons [4, 5]. As a consequence, lattice thermal conductivity is not ballistic and electric resistivity displays a T2 behavior driven by transmission and absorption of acoustic phonons by electrons.

[1] V. Martelli et al., Phys. Rev. Lett. 120, 125901 (2018)
[2] Y. Machida et al., Sci. Adv. 4, eaat3374 (2018)
[3] Y. Machida et al., Science 367, 309 (2020)
[4] A. Jaoui at al., Nature Communications 12, 195 (2021)
[5] A. Joui et al. ArXiv arXiv:2105.08408 (Phys. Rev. X, in press).

9:45 – 10:30 Johanna Erdmenger (Julius-Maximilians-Universitaet Wuerzburg)

Aspects of holographic hydrodynamics for electron fluids in solids

So far, graphene is the material of choice for experimentally realizing hydrodynamic behaviour of strongly coupled electrons in a solid. However, in graphene the effective electron-electron coupling is only of order one, still far away from the infinite coupling limit studied in holographic hydrodynamics using gauge/gravity duality. We propose a new Dirac material, Scandium-substituted Herbertsmithite, in which the electron-electron coupling is enhanced by a factor 3.2 as compared to graphene [1]. Using a holographic approach that involves finite-coupling higher-curvature corrections to the famous holographic result of 1/4 pi for the ratio of shear viscosity over entropy density (eta/s), we then estimate eta/s in the coupling regime of the proposed new material. The associated range of Reynolds numbers even puts turbulent behaviour within reach. - Moreover, I will report on recent results for the Hall viscosity and its impact for electron flows in channel geometries [2]. We find that the Hall viscosity is in direct competition with the Lorentz force and temperature gradient. This leads to a non-monotonic dependence on the magnetic field for both the Hall voltage and Nernst effect.

[1] D. Di Sante, J. Erdmenger, M. Greiter, I. Matthaiakakis, R. Meyer, D. Rodriguez Fernandez, R. Thomale, E. Van Loon and T. Wehling, Nat Commun 11, 3997 (2020).
[2] Z.-Y. Xian, S. Danz, I. Matthaiakakis, D. Rodriguez Fernandez, R. Klees, C. Tutschku, J. Erdmenger, R. Meyer and E. Hankiewicz, to appear.

11:00 – 11:45 Aristomenis Donos (Durham University)

The Higgs/Amplitude Mode from Holography

Second order thermal phase transitions are driven my an order parameter which comes with an amplitude. Fluctuations of this amplitude lead to a slowly decaying mode whose gap closes to zero at the critical point. I will use holographic techniques to discuss in detail how this gapped mode determines the linear response of scalar operators close to the phase transition and give a geometric expression for the dissipative coefficient that fixes the relevant Green’s functions.

11:45 – 12:30 Dominic Else (Harvard University)

Conductivity of metallic quantum critical points

A striking empirical feature of the "strange metals" seen in materials such as cuprates is the scale-invariance of the optical conductivity as a function of frequency and temperature ("omega/T scaling"). In this talk, I carefully analyze the theoretical implications of this property. Through general arguments, I will argue that the only way to achieve such scale-invariant conductivity in a clean compressible system is for there to be critical fluctuations of an order parameter that is odd under inversion and time-reversal symmetry ("loop current order"). In the second part of the talk, I will give analytical results for a familiar model of a metallic quantum critical point, in the "Hertz-Millis paradigm" where a Fermi surface is coupled to a fluctuating boson. In particular, one can study the case of a loop current order parameter, motivated by the above considerations. I show how for certain quantities (including the optical conductivity), one can obtain exact non-perturbative results in the IR limit, in contrast to uncontrolled or pertubative schemes considered previously in the literature.

14:00 – 14:45 Thomas Scaffidi (online) (University of Toronto)

Spread and erase -- How electron hydrodynamics can eliminate the Landauer-Sharvin resistance

What is the ultimate limit of conductance of a metallic device of lateral size W? In the ballistic limit, the answer is the Landauer-Sharvin conductance, which is associated with an abrupt reduction of the number of conducting channels when going from the contacts to the device. However, the ballistic limit is not always the best-case scenario, since adding strong electron-electron scattering can take electrons to a viscous regime of transport for which "super-ballistic" flows were recently studied. In this talk, we will show that by a proper choice of geometry which resembles a "wormhole", it is possible to spread the Landauer-Sharvin resistance throughout the bulk of the system, allowing its complete elimination by electron hydrodynamics. This effect arises due to the interplay between geometry and strong electron-electron scattering, which allows for a net transfer of carriers from reflected to transmitted channels. Finally, we will discuss a recent experiment in a Corbino geometry which realizes one half of this "wormhole" geometry.

Refs:
Theory: "Spread and erase -- How electron hydrodynamics can eliminate the Landauer-Sharvin resistance" Stern et al arXiv:2110.15369
Experiment: "Imaging Hydrodynamic Electrons Flowing Without Landauer-Sharvin Resistance" Kumar et al arXiv:2111.06412

14:45 – 15:30 Philip Phillips (University of Illinois, Urbana-Champaign)

Strange Metals and Anomalous Dimensions for Conserved Currents from Noether's Second Theorem

The unsaturating resistivity exceeding the Ioffe-Regel-Mott bound in the strange metal phase of the cuprates implies that electrons are not the propagating degrees of freedom. The search for new degrees of freedom has led some to conclude that not only does the relevant gauge field that describes the interactions with electromagnetic radiation have an anomalous dimension but so does the current. This conclusion flies in the face of the well known result in quantum field theory that conserved quantities do not acquire anomalous dimensions under any amount of renormalization. My talk will focus on demistifying the claim of anomalous dimensions of conserved quantities. I will show that N\"other's Second Theorem allows for electromagnetisms in which the conserved current and gauge field can actually have arbitrary dimensions. However, I will show that the only quantum theories to date which exhibit such behaviour are holographic models that are derived from a gravity theory that lives in an extra dimension. The boundary actions are constructed using the membrane paradigm and are explicitly non-local.
The existence of currents having anomalous dimensions, a direct probe of the existence of extra dimensions, can be tested with the Aharonov-Bohm effect. I will describe this effect and its potential impact for unlocking the physics of the strange metal in the cuprates.

16:00 – 16:30 Johannes Hofmann (Weizmann Institute of Science)

Superconductivity, charge-density wave and supersolidity in flat-bands with tunable quantum metric

Predicting the fate of an interacting system in the limit where the electronic bandwidth is quenched is often highly non-trivial. The complex interplay between interactions and quantum fluctuations driven by the band geometry can drive a competition between various ground states, such as charge density wave order and superconductivity. In this work, we study an electronic model of topologically-trivial flat bands with a continuously tunable Fubini-Study metric in the presence of on-site attraction and nearest-neighbor repulsion, using numerically exact quantum Monte Carlo simulations. By varying the electron filling and the spatial extent of the localized flat-band Wannier wavefunctions, we obtain a number of intertwined orders. These include a phase with coexisting charge density wave order and superconductivity, i.e., a supersolid. In spite of the non-perturbative nature of the problem, we identify an analytically tractable limit associated with a `small' spatial extent of the Wannier functions and derive a low-energy effective Hamiltonian that can well describe our numerical results.

16:30 – 17:00 Eric Mefford (University of Victoria)

First order hydrodynamic stability of holographic superfluids and the Landau criteria

Long ago, Landau argued that superfluids can exist in nature because their dispersion relations prohibit a flowing normal fluid from dissipating energy into the superfluid below some velocity called the Landau critical velocity. Likewise, it is well-established that at low energies and long wavelengths, superfluids are described by a two-fluid model of hydrodynamics, and it is an important problem to establish the stability of low energy perturbations to the equilibrium state of a superfluid, especially when the normal and superfluid components flow at different velocities. These two problems must be intimately connected in the sense that at long wavelengths, Landau's criteria would manifest itself as a hydrodynamic mode which becomes unstable for equilibrium superflows above some critical velocity. I will discuss how such instabilities arise in superfluid hydrodynamics and demonstrate their existence in the case of holographic superfluids. I will then tie the hydrodynamic results to conventional notions of the Landau criteria for superfluid stability.

Friday, 24 Jun

9:00 – 9:45 Anushya Chandran (Boston University)

TBA

TBA

9:45 – 10:30 Andrew Mackenzie (online) (CPFS, MPG)

Interplay between electronic and elastic degrees of freedom in Sr2RuO4

TBA

11:00 – 11:45 Sean Hartnoll (online) (Cambridge)

Joule Heating in Bad Metals

I will first review why it is important to disentangle the effects of electronic interactions and electron-lattice interactions in unconventional metals. I will then describe an observable process that depends crucially on electron-lattice interactions: the transfer of energy from hot electrons to a cooler lattice. Textbook discussion of this effect build upon weakly interacting electronic quasiparticles and may well not be applicable in bad metals. I will present a formula for rate at which this energy transfer occurs in the absence of quasiparticles. I will illustrate the use of this formula using recent EELS data as well as Monte-Carlo simulations of the Hubbard model.

11:45 – 12:30 Sung-Sik Lee (Perimeter)

Functional renormalization group formalism for non-Fermi liquids and the antiferromagnetic quantum critical metal

We develop a field-theoretic functional renormalization group formalism for non-Fermi liquids and apply it to the anti-ferromagnetic quantum critical metal in two space dimensions. As all gapless degrees of freedom are included within a low-energy effective theory, one can describe momentum-dependent scaling properties of Fermi surface and the emergence of superconductivity within the unified description. Due to the presence of the intrinsic scale set by the Fermi momentum and the associated UV/IR mixing, the notions of renormalizability, low-energy observables and scale invariance need to be generalized from those in relativistic field theories.

Saturday, 25 Jun

13:15 – 14:00 Peter Abbamonte (University of Illinois, Urbana-Champaign)

The current situation with plasmons and the MFL-like continuum as seen by EELS measurements of strange metals

TBA

14:00 – 14:45 Aavishkar Patel (online) (Berkeley)

Universal, low temperature, T-linear resistivity in two-dimensional quantum-critical metals from spatially random interactions

"Strange metal” behavior with T-linear resistivity is observed experimentally down to very low temperatures in many two-dimensional or quasi two-dimensional materials with strongly interacting electrons. Simultaneously, signatures of quantum criticality such as enhanced specific heat capacities and universal “Planckian” electron lifetimes are also observed. I will show, via controlled strong coupling calculations, that all these features universally stem from the effects of spatial disorder on two-dimensional
metallic quantum critical points of pretty much any kind. Importantly, the spatial disorder required for such behavior affects both the kinetic and interaction terms in the Hamiltonian, a feature that is naturally expected in complex materials with microscopic disorder, but not commonly considered by theorists.

14:45 – 15:30 Philip Moll (EPFL)

Field-switchable chiral transport in the Kagome superconductor CsV_3Sb_5

The family AV_3Sb_5 (A=K,Rb,Cs) has shifted into the research focus recently as the chemically clean compounds offer access to a series of electronic correlated states, ranging from charge ordering, superconductivity to rotational symmetry breaking (chirality, nematicity). In addition, time-reversal-symmetry breaking in this has been proposed by muon spectroscopy, despite the absence of large magnetic moments. Furthermore, a mirror-symmetry breaking is observed by scanning tunnelling microscopy (STM), that curiously switches between the enantiomers upon reversing the direction of an applied magnetic field. We probe the out-of-plane transport signatures by Focused Ion Beam machining of micro-wires from cross-sections of the thin, plate-like crystals. These experiments present CsV_3Sb_5 as a rather remarkable correlated conductor, with two unusual properties: First, the in-plane magnetoresistance just above the CDW transition (T~94K) is unmeasurably small, yet it suddenly increases by orders of magnitude once the sample enters the low-temperature state. This highlights the appearance of small, closed 3D Fermi surfaces at the CDW formation, a result of its 3D nature despite the layeredness of the material. Second, under finite magnetic field a strong non-reciprocal transport is observed that points towards a chiral state of the conductor, with an unusually strong coupling of this chiral object to the conduction process. Unlike all other chiral conductors, the enantiomer is not statically selected by the crystal structure, but can be reversed by reversing the field direction – in a phenomenology reminiscent of the STM observations. This points to a strong coupling of a chiral object in the charge ordered state of CsV_3Sb_5 to magnetic fields, in line with the observations of time-reversal symmetry breaking and the consecutive proposals of exotic correlated states such as loop currents.

[1] X. Huang et al., arXiv:2201.07780 (2022)
[2] C. Guo et al., arXiv:2203.09593

16:00 – 16:30 Vaios Ziogas (Ecole Polytechnique)

Damping of Pseudo-Goldstone Fields

Approximate symmetries abound in Nature. If these symmetries are also spontaneously broken, the would-be Goldstone modes acquire a small mass and are referred to as pseudo-Goldstones. At nonzero temperature, the effects of dissipation can be captured by hydrodynamics at sufficiently long scales. In this talk, we show that in the limit of weak explicit breaking, locality of hydrodynamics implies that the damping of pseudo-Goldstones is completely determined by their mass and certain diffusive transport coefficients. We explicitly demonstrate this mechanism in the case of superfluids, and we also discuss possible experimental relevance in strange metal high Tc superconductors.

16:30 – 17:00 Mikael Fremling (Utrecht University)
Sachdev-Ye-Kitaev physics in strained honeycomb iridates

I will discuss the possibility of having Sachdev-Ye-Kitaev (SYK) physics in strained honeycomb iridates.
The SYK model needs three ingredients - Majoranas, flat bands, and random all-to-all interactions. The idea is quite simple: Some iridate materials can be modeled with the Kitaev Honeycomb model, and the low energy degrees of freedom are not spins but rather Majorana fermions. By applying strain, the kinetic energy of the Majoranas is quenched, creating flat bands. Finally, taking into account sample impurities and residual Heisenberg interactions, the random all-to-all interactions between the Majoranas will emerge.
In our implementation of the above-described idea, we find a bipartite-cousin of the SYK model, which has tunable scaling dimensions and modified level statistics.

Sunday, 26 Jun

9:00 – 9:45 Paolo Glorioso (Stanford University)
Breakdown of hydrodynamics in fracton fluids

Many-body systems whose constituents have restricted mobility have attracted considerable attention recently. A prominent example of such systems are fractons, where the restricted mobility is controlled by symmetry principles. In the context of hydrodynamics it has been shown theoretically, and confirmed experimentally, that such restricted mobility leads to novel scaling behaviours in the macroscopic dynamics. In this talk, I will introduce a framework to describe the hydrodynamics of fractons and predict such scaling laws, with particular focus on systems with conserved dipole and momentum. This hydrodynamics turns out to have rather exotic properties, owing to the fact that translation invariance leads to a non-trivial extension of spacetime symmetries. After developing an effective theory approach that allows accounting for fluctuations, I will show that such theory contains relevant nonlinearities that lead to the emergence of a novel stochastic non-Gaussian universality class, thus constituting a breakdown of the local hydrodynamic description.

9:45 – 10:30 Edwin Huang (University of Illinois at Urbana Champaign)

Fluctuating intertwined stripes in the strange metal regime of the Hubbard model

Strongly correlated electron systems host a variety of poorly understood correlations in their high temperature normal state. Unlike ordered phases defined by order parameters, regions of the normal state are often defined through unconventional properties such as strange metallic transport or spectroscopic pseudogaps. Characterizing the microscopic correlations in the normal state is necessary to elucidate mechanisms that lead to these properties and their connection to ground state orders. Here we establish the presence of intertwined charge and spin stripes in the strange metal normal state of the Hubbard model using determinant quantum Monte Carlo calculations. The charge and spin density waves constituting the stripes are fluctuating and short-ranged, yet they obey a mutual commensurability relation and remain microscopically interlocked, as evidenced through measurements of three-point spin-spin-hole correlation functions. Our findings demonstrate the ability of many-body numerical simulations to unravel the microscopic correlations that define quantum states of matter.

11:00 – 11:45 Ipsita Mandal (IFJ PAN)

Correlated States in Triangular Moiré Superlattices

Experiments on graphene bilayers, where the top layer is rotated with respect to the one below, have displayed insulating behavior when the moiré bands are partially filled. In the first part of the talk, I will elaborate on our calculations to find the static charge configurations in these phases, and to estimate the excitation gaps.
In the second part of the talk, I will focus on the properties of a metal in a triangular lattice that undergoes a quantum phase transition to a valley-polarized nematic state. Besides breaking the threefold rotational symmetry of the triangular moiré superlattice, this type of order also breaks twofold rotational and time-reversal symmetries. At zero temperature, the ordered state displays a pseudo-Goldstone mode due to the existence of a dangerously irrelevant coupling λ in the 6-state clock model that describes the valley-polarized nematic quantum critical point. Using a two-patch model, we compute the fermionic self-energy to show that down to very low energies, the Yukawa-like coupling between the pseudo-Goldstone mode and the electronic degrees of freedom promotes the emergence of non-Fermi liquid behavior. Below a crossover energy scale, Fermi liquid behavior is recovered.

11:45 – 12:30 Benjamin Withers (University of Southampton)

Does the hydrodynamic expansion converge?

As an effective theory of conserved currents near equilibrium, relativistic hydrodynamics is of wide applicability. However it is formulated as a gradient expansion whose properties are poorly understood. I will give an overview of recent developments understanding the large-order behaviour of this expansion and present evidence that it is a divergent series in general. I will show that the divergence is controlled by a new collective field called a singulant and discuss its physical interpretation.

14:00 – 14:45 Matteo Mitrano (Harvard University)

Ultrafast manipulation of electronic interactions in quantum materials

Intense ultrashort electromagnetic fields are an increasingly important tool to realize and control novel emergent phases in quantum materials. Among a variety of nonthermal excitation pathways, a particularly intriguing route is represented by the direct light-engineering of effective many-body interactions, such as electron hopping amplitudes and electron-electron repulsion. Achieving a light-induced dynamical renormalization of the screened onsite Coulomb repulsion (“Hubbard U”) would have far-reaching implications for high-harmonic generation, attosecond spectroscopy and ultrafast magnetism in the solid state. However, experimental evidence for a dynamically controlled Hubbard U remains scarce. In this talk, I will present a recent demonstration of light-induced renormalization of the Hubbard U in a high-temperature superconductor, La2-xBaxCuO4, [1] and discuss its implications for the control of superconductivity, magnetism, as well as to the realization of other long-range-ordered phases in light-driven quantum materials. Further, I will discuss the application of these methods to the control of quasi-1D correlated electron systems with long-ranged Coulomb interaction, such as Sr2CuO3.

References

[1] D. R. Baykusheva et al. Phys. Rev. X 12, 011013 (2022).

14:45 – 15:30 Mike Blake (University of Bristol)

On systems of maximal quantum chaos

A remarkable feature of chaos in many-body quantum systems is the existence of a bound on the quantum Lyapunov exponent. An important question is to understand what is special about maximally chaotic systems which saturate this bound. Here I will discuss a proposal for a `hydrodynamic' origin of chaos in such systems, and discuss hallmarks of maximally chaotic systems. In particular I will discuss how in maximally chaotic systems there is a suppression of exponential growth in commutator squares of generic few-body operators. This suppression appears to indicate that the nature of operator scrambling in maximally chaotic systems is fundamentally different to scrambling in non-maximally chaotic systems.

Program block 2

Tuesday, 28 Jun

11:00 – 12:00 Ulf Gran (Chalmers University of Technology)

A holographic model for surface plasmon-polaritons

In recent years the dynamical charge response of the strange metal phase in high temperature superconductors have become experimentally accessible. We construct a holographic model for the interface between a strange metal and a dielectric and study the collective modes. We focus on the surface plasmon-polariton and present preliminary results regarding its dispersion relation and discuss the possible connection to experiments.

14:00 – 15:00 Arkady Shehter (Los alamos nation laboratory)

Strange metal phenomenology and the Hall resistivity in the cuprates.

The anomalous transport behavior—both longitudinal and Hall—is the defining characteristic of the strange-metal state of High-Tc cuprates. The temperature- , frequency-, and the magnetic field dependence of the resistivity is understood within strange metal phenomenology as resulting from energy scale competition to set the inelastic relaxation rate. The anomalously strong temperature dependence of the Hall coefficient in the strange metal state of cuprates famously fall out of such physical picture. I will discuss our recent measurements of the Hall resistivity in the strange metal state of cuprates in a broad range of magnetic fields and temperatures. The observed field- and temperature dependence Hall resistivity at very high magnetic fields reveals a distinct high-field regime which is controlled by an energy-scale competition over a broad range of magnetic fields and temperatures. This extends the strange metal phenomenology in the cuprates and suggests, in particular, that direct effect of magnetic field on the relaxation dynamics of quantum fluctuations might, at least partially, be responsible for the anomalous Hall resistivity behavior in the in the strange metal state of the cuprates.

11:00 – 12:00 Nigel Hussey (High Field Magnet Laboratory (HFML-EMFL) and Institute for Molecules and Materials, Radboud University; H. H. Wills Physics Laboratory, University of Bristol)

Dual character of the cuprate strange metal

It has long been recognized that the key to unlocking the mystery of cuprate high-Tc superconductivity lies in understanding the anomalous normal state from which pairs form and condense. While many of its defining properties – linear-in-temperature resistivity, linear-in-field magnetoresistance (MR) at high fields, quadratic-in-temperature inverse Hall angle and modified Kohler's rule – have been identified, they are often considered either at a singular doping level or as an isolated phenomenon as a function of doping. As a result, their relation to each other and to the pseudogap, strange metal and non-superconducting regimes that define the cuprate phase diagram has yet to be elucidated. In this presentation, I will describe my group's recent efforts to delineate all three regimes via studies of the (magneto)-transport properties of hole-doped cuprates in high magnetic fields up to 70 Tesla [1-3]. By investigating three distinct families of hole-doped cuprates - Tl2Ba2CuO6+δ, La2-xSrxCuO4 and La/Pb-doped Bi2Sr2CuO6+δ – a common picture begins to emerge of two charge sectors coexisting within the strange metal phase of overdoped cuprates, one describable by conventional Boltzmann transport theory [4], the other not [2]. Curiously, as the contribution from the latter grows with reduced doping, so too does the superconducting condensate [5]. Finally, a link is established between the quadrature scaling of the magnetoresistance at high field strengths and the so-called separation of lifetimes seen at low-fields [3].

Reference

[1] C. Putzke et al., Nature Physics 17, 185-189 (2021)
[2] J. Ayres, M. Berben et al., Nature 595, 661-666 (2021)
[3] M. Berben, J. Ayres et al., arXiv:2203.04867 (2022)
[4] R. D. H. Hinlopen et al., arXiv:2201.03292 (2022)
[5] M. Čulo, C. Duffy et al., SciPost Physics 11, 012 (2021)

14:00 – 15:00 Steven Kivelson (Stanford)

TBA

TBA

Thursday, 30 Jun

11:00 – 12:00 Francisco Pena-Benitez (Wroclaw University of Science and Technology)

Spacetime symmetries and Fractons

Symmetric gauge fields mediate the interaction between certain classes of fracton excitations. However, the global symmetries associated with those theories are peculiar because they restrict the free movement of fractons. The main property is a non-trivial algebra between spacetime generators and "internal" charges. In this talk, I will introduce the (ideal) hydrodynamic regime of dipole preserving theories, and discuss the properties of symmetric gauge theories on generic curved backgrounds.

14:00 – 15:00 Jan Zaanen (Leiden University)

Quantum supreme matter and the strange metals.

Quantum supreme matter refers to forms of matter that are densely many-body entangled with the ramification that the quantum supremacy of the quantum computer is required to enumerate the way it works. Prime candidates are the strange metals, in particular those observed in cuprates. I will present the case that holography yields a mathematical view on generic properties of such states of matter. In particular, it gives away a generalization of the universality principle associated with strongly interacting “stoquastic” quantum critical states to the realms of finite density fermion matter. This revolves around a “covariant” renormalization group flow revealed by holography showing how the Fermi-liquid generalizes into a densely many-body entangled affair [1], revealing the finite temperature physics through a “first principle” treatment of quantum thermalization. Guided by these insights, substantial progress has been made in recognizing various of these traits in experiments on the strange metal states of the high Tc superconductors.

References

[1]. J. Zaanen, arXiv:2110.00961 (2021).

Friday, 01 Jul

11:00 – 12:00 Christiana Pantelidou (University College Dublin)

Dissipation in Holographic Superfluids

This talk will focus on the study of strongly coupled superfluids in the hydrodynamic regime, where the universal behaviour of the system at long wavelengths is packaged in a set of transport coefficients. In particular, I will discuss the computation of transport coefficients in a simple model of holographic superfluidity, taking advantage of the symplectic current in order to get analytic results. If time allow, I will briefly indicate how this can be generalised for inhomogeneous strongly coupled superfluids.

14:00 – 15:00 Zhi-Xun Shen (Stanford University, SLAC, * On sabbatical as the Tage Erlander Visiting Professor at KTH, Sweden)

Recent results and reflections on the cuprate phase diagram

A recent finding of a sharp and almost “vertical boundary” of the strange metal state adds to the riches of the cuprate electronic phase diagram [1]. In this talk, I will present recent angle-resolved photoemission data to reveal this effect, and to reflect on a few peculiarities around it: i) the smooth sailing of pairing temperature across this boundary[1], contrasting to the rapid change of pairing energy gap near this boundary [2,3]; ii) the ubiquitous and strong phase fluctuation[4,5]; iii) evidence of competition between superconducting pairing and likely another ordering tendency[6].

[1] S.D. Chen et al., Science, 366, 6469 (2019)
[2] Yu He et al., Science, 362, 62 (Oct. 2018)
[3] I.M. Vishik et al., PNAS 109/45, 18332 (2012)
[4] S.D. Chen et al., Nature 601, 562-567 (2022)
[5] Yu He et al. Phys. Rev. X 11, 031068 (2021)
[6] M. Hashimoto et al., Nature Physics 10, 483 (2014)

Saturday, 02 Jul

11:00 – 12:00 Erez Berg (Weizmann Institute of Science)

Exotic superconductivity in graphene multilayers

TBA

14:00 – 15:00 Piers Coleman (Rutgers University)

A solvable 3D Kondo lattice exhibiting odd-frequency pairing and order fractionalization.

The Kondo lattice model plays a key role in our understanding of quantum materials, but a lack of small parameters has posed a long-standing problem. We present a 3 dimensional S= 1/2 Kondo lattice model describing a spin liquid within an electron sea. Strong correlations in the spin liquid are treated exactly, enabling a controlled analytical approach. Like a Peierls or BCS phase, a logarithmically divergent susceptibility leads to an instability into a new phase at arbitrarily small Kondo coupling. Our solution captures a plethora of emergent phenomena, including odd-frequency pairing, pair density wave formation and order fractionalization. The ground-state state is a pair density wave with a fractionalized charge e, S = 1/2 order parameter, formed between electrons and Majorana fermions.

[1] “Order Fractionalization in a Kitaev-Kondo model,”A. M. Tsvelik and P. Coleman, (2021), arXiv:2112.07781.
[2] "A solvable 3D Kondo lattice exhibiting odd-frequency pairing and order fractionalization", Piers Coleman, Aaditya Panigrahi and Alexei Tsvelik, arXiv: 2203.04104